Electronic Supplementary Information

Towards 1D supramolecular chiral assemblies based on porphyrin-calixarene complexes

Massimiliano Gaeta,*[a] Chiara M. A. Gangemi,[b] Matteo Barcellona,[a] Gabriele Travagliante,[a] Marco Milone,[b] Anna Notti,*[b] Maria E. Fragalà,[a] Ilenia Pisagatti,[b] Melchiorre F. Parisi,[b] Roberto Purrello[a] and Alessandro D'Urso*[a]

[a]*Dipartimento di Scienze Chimiche, Università degli Studi di Catania, Viale A. Doria 6, 95125 Catania, Italy. E-mail: adurso@unict.it, gaetamassimiliano@libero.it*

[b]*Dipartimento di Scienze Chimiche, Biologiche, Farmaceutiche ed Ambientali, Università degli Studi di Messina, V.le F. Stagno d'Alcontres 31, 98166 Messina, Italy. E-mail: anotti@unime.it*

Experimental:

Commercial reagent grade chemicals were used as received without any further purification. Solvents were dried by standard methods. Melting points were determined on a Kofler hot stage apparatus and are uncorrected. ^{1}H and ^{13}C NMR (Attached Proton Test, APT) spectra were acquired at 25 °C at 500 and 125 MHz, respectively. Chemical shifts are reported in ppm and are referenced to residual solvent peaks (δ_H = 7.27 ppm and δ_C = 77.0 ppm for $CDCl_3$), (δ_H = 3.31 ppm for CD_3OD) or dioxane (δ_H = 3.53 ppm and δ_C= 66.3 ppm) added as an internal standard. Samples for high resolution mass spectrometry (HRMS) analyses were diluted in methanol HPLC-MS grade (final concentration 5 μM) and directly injected into a Xevo G2-XS Q-ToF mass spectrometer (Waters Corporation, Wilmslow, UK) equipped with a REIMS source HRMS (ESI)analyses were performed both in positive and negative ionization mode over a mass range of 100–1800 *m/z* with a scan time of 0.5 s.

Synthetic procedures:

Trisulfonated-diphenyl porphyrin **H_2DPPS3**:

H_2DPPS3 was obtained according to a slightly modified literature procedure.[S1] 5,15-Diphenylporphine[S2] (80 mg, 0.17 mmol) was sulfonated with 98% H_2SO_4 (15 mL) at 100°C for 4 h. The reaction mixture was let to reach r.t., diluted with water (80 mL), neutralized with K_2CO_3 and then the unreacted porphyrin was extracted with CH_2Cl_2. The aqueous phase was filtered through a nylon membrane of 0.8 μm pore diameter. The solid residue on the filter was solubilized with methanol. The crude product was purified by reverse phase column chromatography (RP-18; MeOH/H_2O, 4:1) to yield 45 mg (0.05 mmol, 32%) of the title compound. ^{1}H NMR (CD_3OD) δ 11.20 (s, 1 H, *meso*-H) and 10.46 (s, 1 H, *meso*-H), 9.66 (d, *J* = 4.5 Hz, 1 H, β-pyrrolic), 9.61 (d, *J* = 4.5 Hz, 1 H, β-pyrrolic), 9,.43 (d, *J* = 4.5 Hz, 1 H, β-pyrrolic), 9.24 (s, 1 H, β-pyrrolic), 9.15 (d, *J* = 4.5 Hz, 1 H, β-pyrrolic), 9.13 (d, *J* = 4.5 Hz, 1 H, β-pyrrolic), 8.96 (d, *J* = 4.5 Hz, 1 H, β-pyrrolic), 8.34 (m, 8 H, H_m and H_o). HRMS (ESI) m/z: 233.0118 ($[M-3H]^{3-}$, calcd for $C_{32}H_{19}N_4O_9S_3^{3-}$: 233.0110).

N,*N*'-bis(5,11,17,23-tetranitro-25,26,27-tripropoxy-28-[3-carbonylpropoxy]calix[4]arene)-1,2-diaminocyclohexane ((*S,S*)-**8NO_2-BC4** and (*R,R*)-**8NO_2-BC4**):

(*R*,*R*)-**8NO_2-BC4**. 25-(3-Chlorocarbonylpropoxy)-5,11,17,23-tetranitro-26,27,28-tripropoxycalix[4]arene **1**[S3] (309 mg, 0.37 mmol) was dissolved in anhydrous CH_2Cl_2 (5 mL) and cooled to –10 °C. To this solution a mixture of (1*R*,2*R*)-(–)-1,2-diaminocyclohexane (21 mg, 0.18 mmol) and triethylamine (38 mg, 0.37 mmol) in anhydrous CH_2Cl_2 (2 mL) was added *via* a cannula. The reaction mixture was stirred overnight at room temperature. After the addition of water (5 mL), the product was extracted with CH_2Cl_2 and dried over Na_2SO_4. The solid obtained after evaporation of the solvent was dissolved in CH_2Cl_2 (5 mL) containing triethylamine (0.1 mL) and the final solution evaporated to dryness. The crude mixture was then subjected to column chromatography (SiO_2, cyclohexane/AcOEt 2:1) to give pure (*R*,*R*)-**8NO_2-BC4** in the form of a pale yellow solid (225 mg, 71%), mp 247–250 °C. ^{1}H NMR ($CDCl_3$) δ 7.74 (s, 4 H), 7.72 (s, 4 H), 7.35 (s, 4 H), 7.29 (s, 4 H), 6.15 (bd, 2 H), 4.52 (d, *J* = 14.0 Hz, 4 H), 4.50 (d, *J* = 13.6 Hz, 2 H), 4.48 (d, *J* = 14.3 Hz, 2 H), 4.05–3.96 (m, 12 H), 3.90 (t, *J* = 7.2 Hz , 4 H), 3.60 (broad t, 2 H), 3.41 (d, *J* = 14.4 Hz, 4 H), 3.39 (d, *J* = 14.0 Hz, 2 H), 3.38 (d, *J* = 13.5 Hz, 2 H), 2.22–2.11 (m, 8 H), 2.01 (d, *J* = 11.7 Hz, 2 H), 1.95–1.85 (m, 12 H), 1.76 (d, *J* = 7.7 Hz, 2 H), 1.32–1.18 (m, 4 H), 1.06 (t, *J* = 7.5 Hz, 6 H), 0.98 (t, *J* = 7.4 Hz, 12 H) ppm; ^{13}C NMR ($CDCl_3$) δ

S1 R. Rubires, J. Crusats, Z. El-Hachemi, T. Jaramillo, M. López, E. Valls, J.-A. Farrera and J. M. Ribó, *New J. Chem*., 1999, **23**, 189–198.

S2 F. Gou, X. Jiang, R. Fang, H. Jing and Z. Zhu, *ACS Appl. Mater. Interfaces* 2014, **6**, 6697–6703.

S3 G. Gattuso, G. Grasso, N. Marino, A. Notti, A. Pappalardo, S. Pappalardo and M. F. Parisi, *Eur. J. Org. Chem.*, 2011, 5696–5703.

172.2, 162.12, 162.10, 161.3, 161.1, 142.76, 142.74 (×3), 135.92, 135.91, 135.8 (×2), 135.06, 135.02, 135.00, 134.99, 124.4 (×2), 124.3, 124.2, 123.62, 123.60, 123.55, 123.50, 77.8, 77.7, 77.6, 75.1, 53.9, 32.4, 32.2, 31.12, 31.08, 25.9, 24.5, 23.3, 23.2, 10.3, 10.01, 10.0 ppm. MALDI *m/z* = 1734.8 $[M+Na]^+$.

(*S*,*S*)-**8NO$_2$-BC4**. Obtained in a similar manner as (*R*,*R*)-**8NO$_2$-BC4** and with comparable yields. The NMR spectra of (*S*,*S*)-**8NO$_2$-BC4** are identical to those of its mirror image (*R*,*R*)-**8NO$_2$-BC4**.

N,*N*'-bis(5,11,17,23-tetraamino-25,26,27-tripropoxy-28-[3-carbonylpropoxy]calix[4]arene)-1,2-diaminocyclohexane ((*S,S*)-**8NH$_2$-BC4** and (*R,R*)-**8NH$_2$-BC4**):

(*R,R*)-**8NH$_2$-BC4**. A suspension of diamide (*R*,*R*)-**8NO$_2$-BC4** (50 mg, 0.029 mmol) and Ni/Raney in THF (10 mL) was stirred at room temperature for 18 h under H_2 (1 atm) and then filtered over celite. The solvent was evaporated under reduced pressure and the solid residue formed was triturated with cyclohexane and then filtered, to provide the octaamine derivative (37 mg, 0.025 mmol, 86%) which was used in the next step without further purification. ^{1}H NMR ($CDCl_3$) δ 6.09, 6.08, 6.03, 5.99 (4 × s, 4 H each), 5.80 (d, *J* = 7.3 Hz, 2 H), 4.30 (d, *J* = 13.3 Hz, 4 H), 4.27 (d, *J* = 13.2 Hz, 2 H), 4.26 (d, *J* = 13.2 Hz, 2 H), 3.78–3.69 (m, 16 H), 3.61 (broad t, 2 H), 3.8–2.8 (hump, 16 H), 2.92 (d, *J* = 13.2 Hz, 8 H), 2.2–1.7 (m, 24 H), 1.33–1.18 (m, 4 H), 0.96, 0.94, 0.93 (3 × t, *J* = 7.0 Hz, 6 H each) ppm. MALDI *m/z* = 1495 $[M+Na]^+$.

(*S,S*)-**8NH$_2$-BC4**. Obtained in a similar manner as (*R,R*)-**8NH$_2$-BC4** and with comparable yields. The NMR spectrum of (*S,S*)-**8NH$_2$-BC4** is identical to that of its mirror image (*R,R*)-**8NH$_2$-BC4**.

N,*N*'-bis(5,11,17,23-tetraamino-25,26,27-tripropoxy-28-[3-carbonylpropoxy]calix[4]arene)-1,2-diaminocyclohexane octahydrochloride ((1*R*,2*R*)- and (1*S*,2*S*)-**BC4**):

(*R,R*)-**BC4**. Addition of an excess of 4 M HCl in dioxane (0.5 mL) to a solution of (*R,R*)-**8NH$_2$-BC4** (37 mg, 0.025 mmol) in CH_2Cl_2 (1 mL) afforded, after solvent evaporation, (*R*,*R*)-**BC4** in quantitative yields. ^{1}H NMR (D_2O) δ 6.67, 6.47 (2 × s, 8 H each), 4.29 (d, *J* = 13.6 Hz, 2 H), 4.28 (d, *J* = 13.6 Hz, 2 H), 4.26 (d, *J* = 13.6 Hz, 2 H), 4.24 (d, *J* = 13.5 Hz, 2 H), 3.82–3.64 (m, 16 H), 3.39 (broad s, 2 H), 3.15 (d, J = 13.9 Hz, 8 H), 2.12 (m, 4 H), 2.00 (m, 4 H), 1.74–1.65 (m, 14 H), 1.54 (bs, 2 H), 1.10 (broad s, 4 H), 0.782 (t, J = 7.3, 6 H), 0.775 (t, J = 7.3, 6 H), 0.765 (t, J = 7.4, 6 H) ppm; ^{13}C NMR (D_2O) δ 175.4, 157.4, 157.07, 156.97, 156.94, 137.5 (×2), 137.4, 137.3, 137.03, 137.00, 136.8, 136.7, 125.1, 124.92, 124.90, 124.7, 123.3, 123.1, 122.8, 122.7, 78.0, 77.9, 77.8, 75.0, 53.6, 33.3, 32.3, 30.9 (×2), 26.5, 24.8, 23.6 (×2), 23.5, 10.58, 10.57, 10.4 ppm. HRMS (ESI) m/z: 736.4448 ($[M+2H]^{2+}$, calcd for $C_{88}H_{116}N_{10}O_{10}^{2+}$: 736.4432); 747.4373 ($[M+H+Na]^{2+}$, calcd for $C_{88}H_{115}N_{10}O_{10}Na^{2+}$: 747.4342); 758.4268 ($[M+2Na]^{2+}$, calcd for $C_{88}H_{114}N_{10}O_{10}Na_2^{2+}$: 758.4252).

(*S*,*S*)-**BC4.** Obtained in a similar manner as (*R*,*R*)-**BC4**. The NMR spectra of (*S*,*S*)-**BC4** are identical to those of its mirror image (*R*,*R*)-**BC4**. HRMS (ESI) m/z: 736.4453 ($[M+2H]^{2+}$, calcd for $C_{88}H_{116}N_{10}O_{10}^{2+}$: 736.4432); 747.4379 ($[M+H+Na]^{2+}$, calcd for $C_{88}H_{115}N_{10}O_{10}Na^{2+}$: 747.4342); 758.4275 ($[M+2Na]^{2+}$, calcd for $C_{88}H_{114}N_{10}O_{10}Na_2^{2+}$: 758.4252).

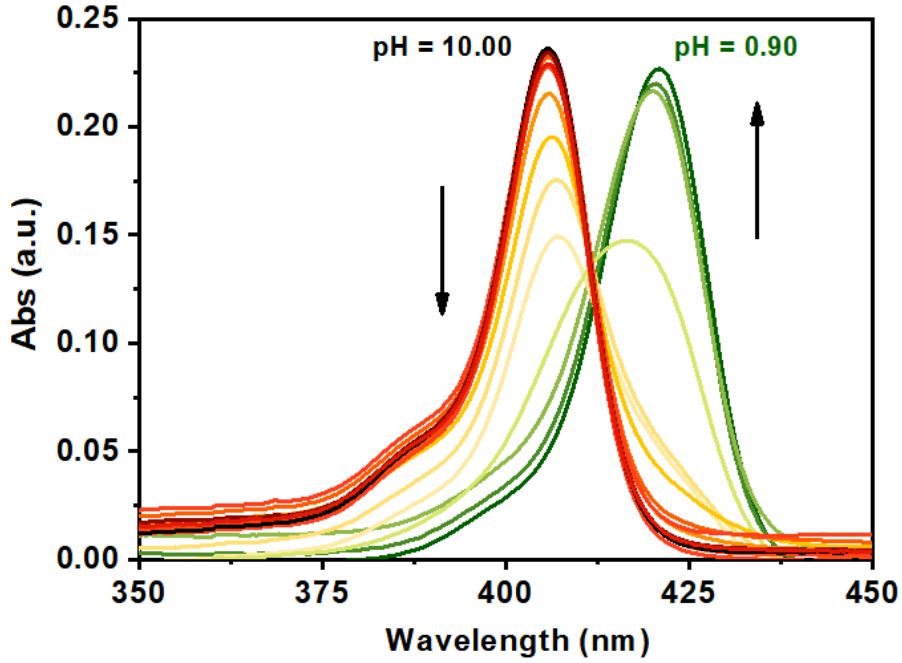

Fig. S1 UV-vis absorption spectra of independent solutions of **H_2DPPS3** (2 µM) at different pH values (pH = 10.00; 8.00; 7.30; 7.10; 6.47; 6.05; 5.86; 4.92; 4.59; 3.91; 3.60; 3.50; 2.44; 1.88; 1.36; 0.9).

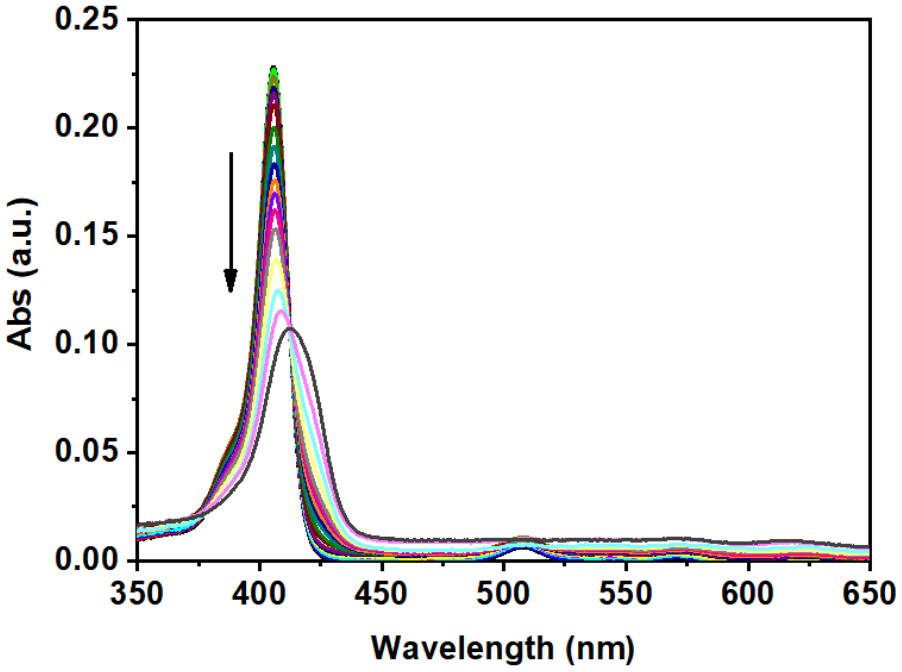

Fig. S2 UV-vis absorption spectra of an aqueous solution of **H_2DPPS3** (2 µM) during the pH titration (pH = 10.00; 9.77; 9.50; 9.00; 8.40; 7.12; 6.55; 6.17; 5.64; 4.88; 4.37; 4.11; 3.80; 3.69; 3.59; 3.47; 3.24; 3.00; 2.74; 2.40).

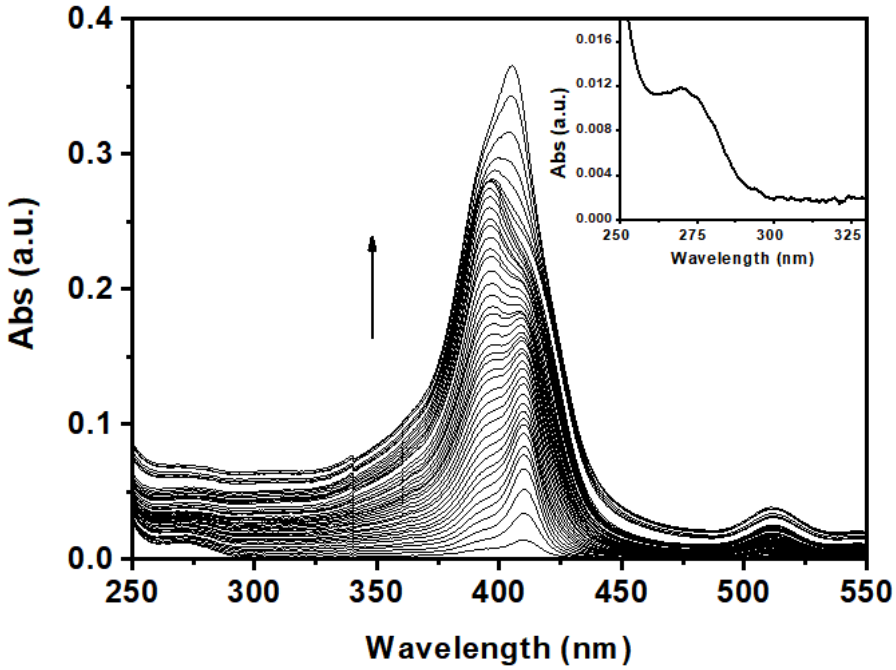

Fig. S3 UV-vis absorption spectra recorded over the course of the titration of a 2.5 µM aqueous solution of **BC_4** at pH 7.00 with successive aliquots of an aqueous solution of **H_2DPPS3** ([**H_2DPPS3**] ranged from 0.25 to 11.0 µM). Inset: UV-vis spectrum of an aqueous solution of **BC_4** (2.5 µM) at pH 7.0.

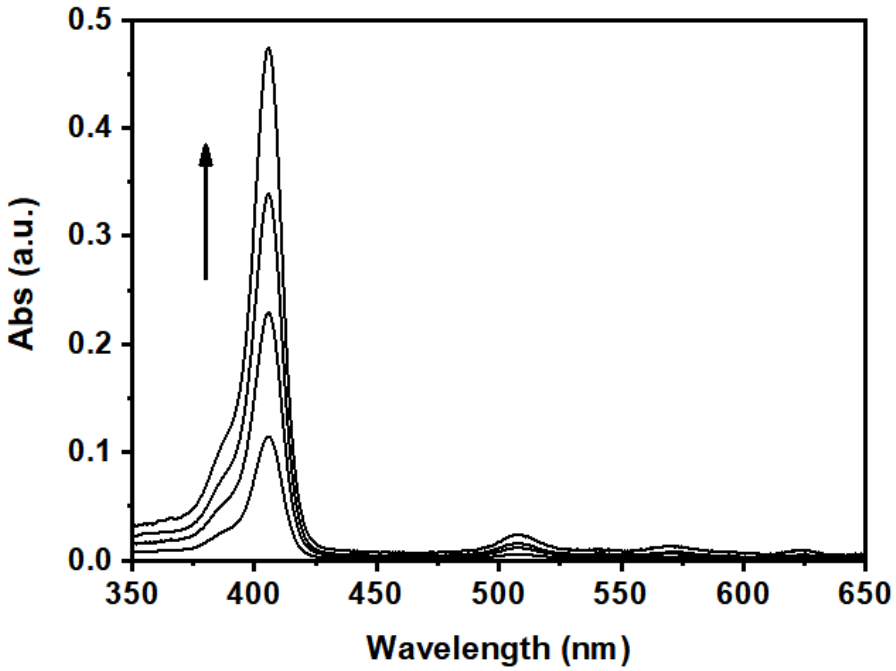

Fig. S4 UV-vis absorption spectra of **H_2DPPS3** in aqueous solution at pH = 7.0 ([**H_2DPPS3**] ranged from 1.0 to 4.0 µM).

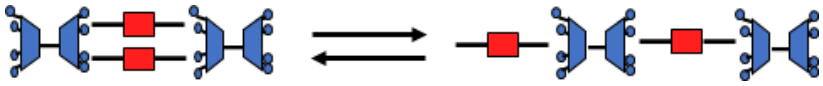

Fig. S5 Likely equilibrium taking place between two different arrangements of the 1:1-(**H_2DPPS3/BC_4**) complex.

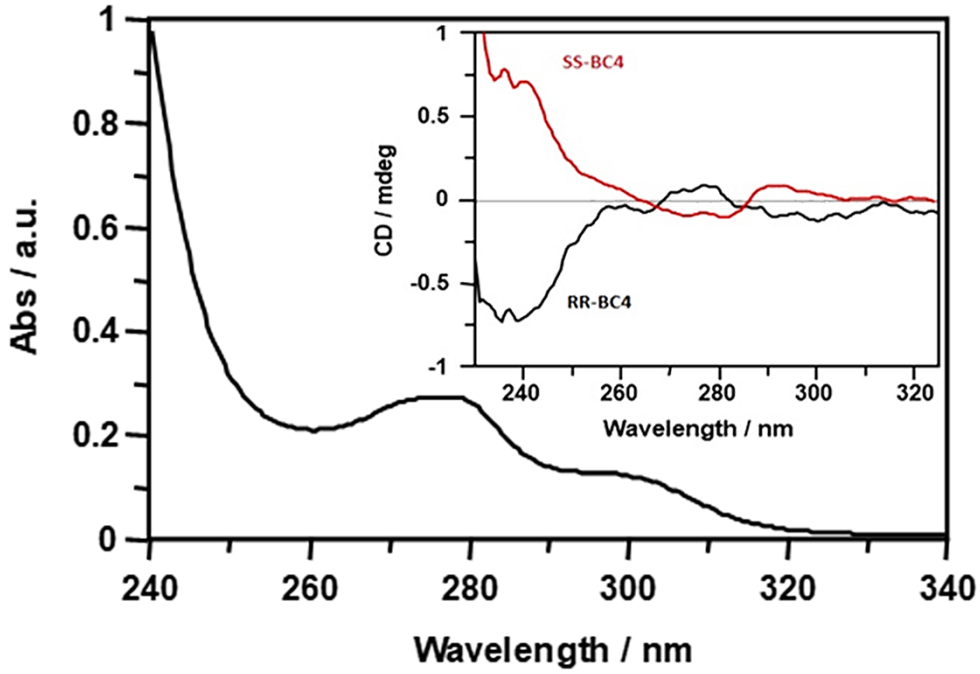

Fig. S6 UV-vis absorption spectrum of an aqueous solution of (*R,R*)- or (*S,S*)-**BC4** (50 µM) at pH 2.0. Inset: Circular dichroism spectra of (*R,R*)- (black trace) or (*S,S*)-**BC4** (red trace) at the same molar concentration and pH value.

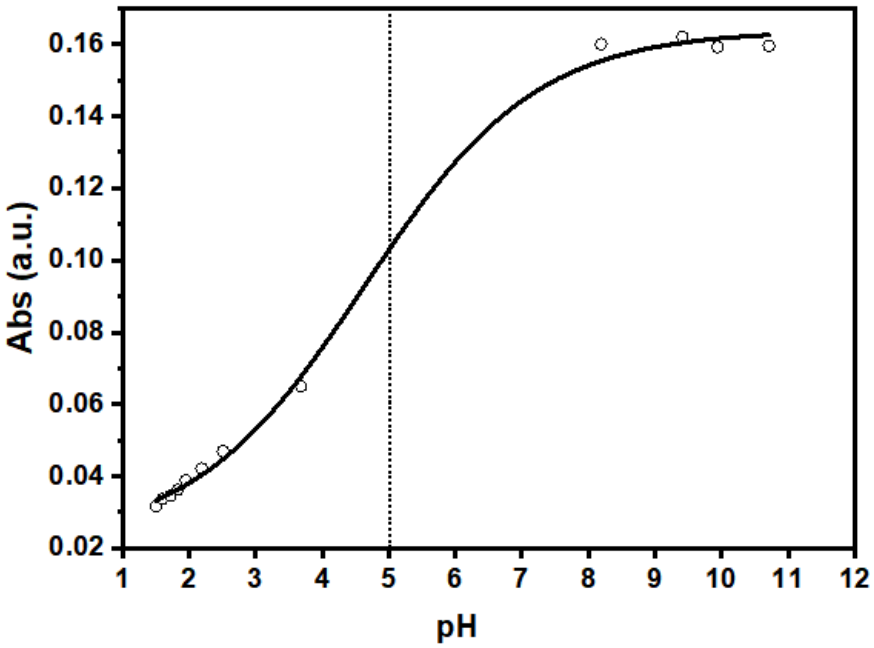

Fig. S7 Plot and experimental fit of the absorbance values at λ = 300 nm (black circles), as function of pH values (pH = 10.70; 9.94; 9.41; 8.19; 3.68; 2.51; 2.19; 1.95; 1.83; 1.72; 1.60; 1.50) of an aqueous solution of (*R,R*)-**8NH$_2$-BC4** (10 μM).

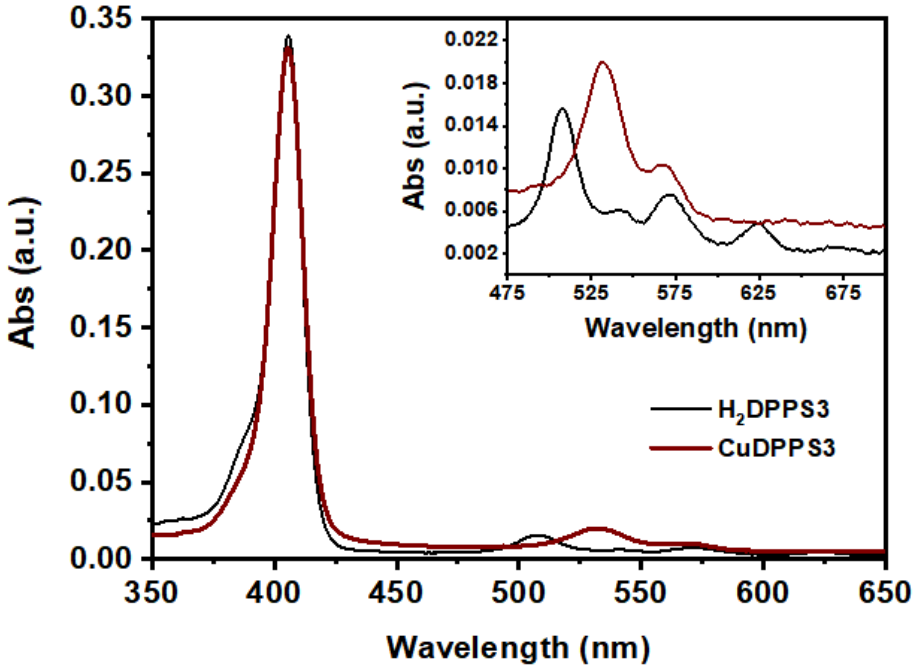

Fig. S8 UV-vis spectra of an aqueous solution of **H$_2$DPPS3** (3 μM) at pH = 10.00 (black traces) and **CuDPPS3** (3 μM) at pH = 10.00 (brown traces). The magnification of the Q-band region is reported in the inset.

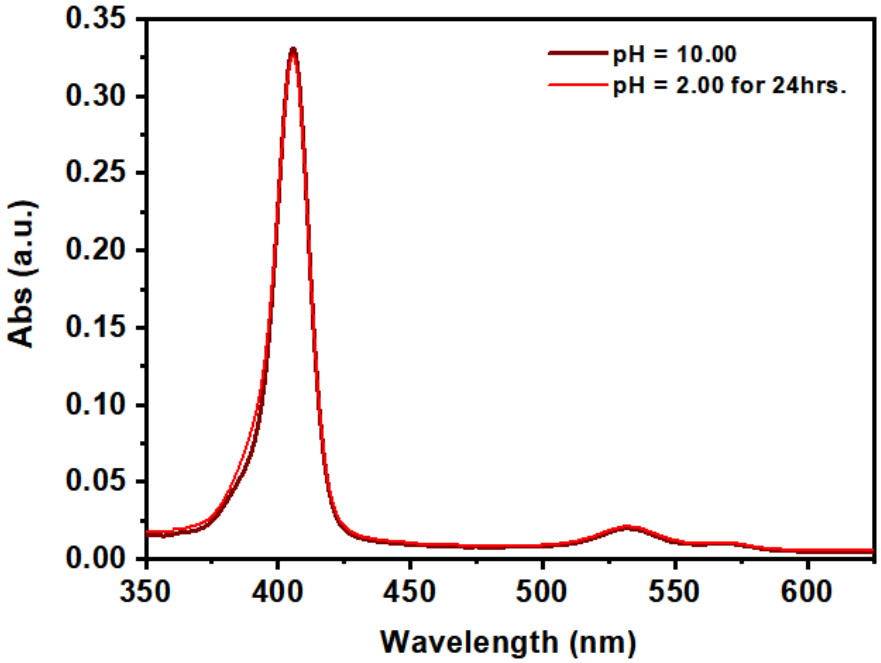

Fig. S9 UV-vis spectra of an aqueous solution of **CuDPPS3** (3 µM) at pH = 10.00 (brown trace) and after 24 hrs. at pH= 2.00 (red trace).

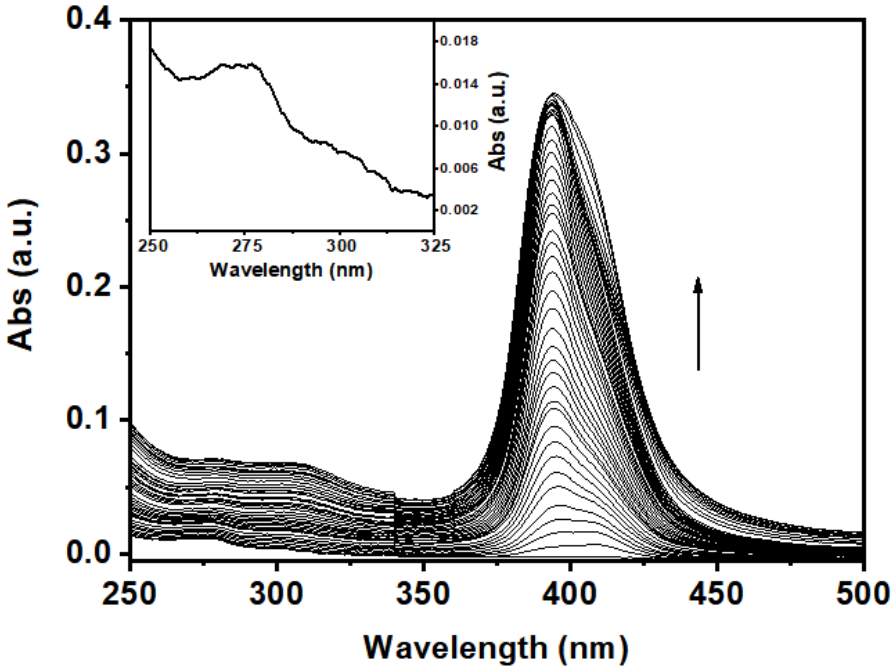

Fig. S10 UV-vis absorption spectra recorded over the course of the titration of a 2.5 µM aqueous solution of (*R,R*)- or (*S,S*)-**BC4** at pH 2.00 with consecutive aliquots of an aqueous solution of **CuDPPS3** ([**CuDPPS3**] ranged from 0.25 to 11.0 µM). Inset: UV-vis spectrum of an aqueous solution of (*R,R*)- or (*S,S*)-**BC4** (2.5 µM) at pH 2.00.

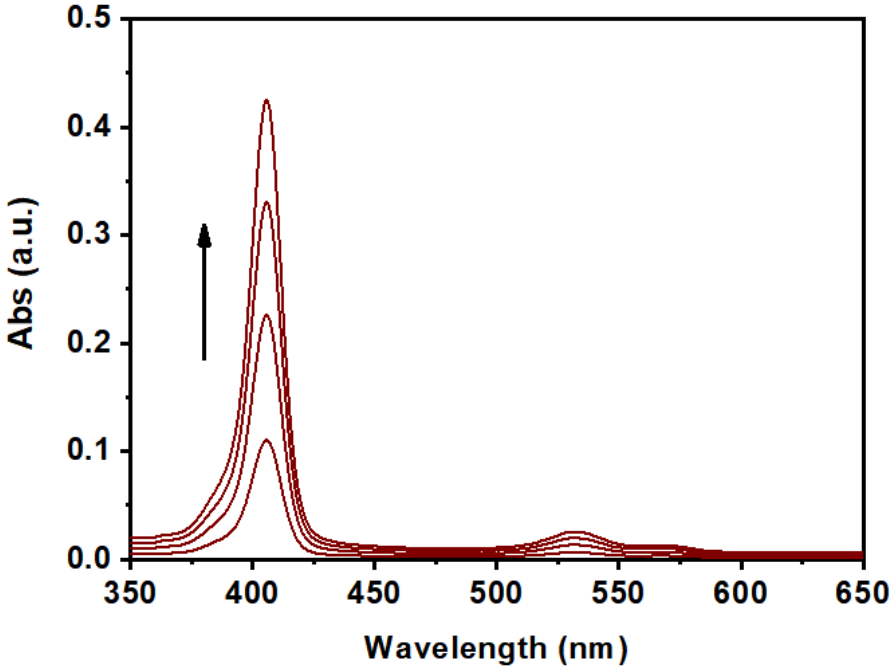

Fig. S11 UV-vis absorption spectra of **CuDPPS3** in aqueous solution at pH = 2.0 ([**CuDPPS3**] ranged from 1.0 to 4.0 µM).

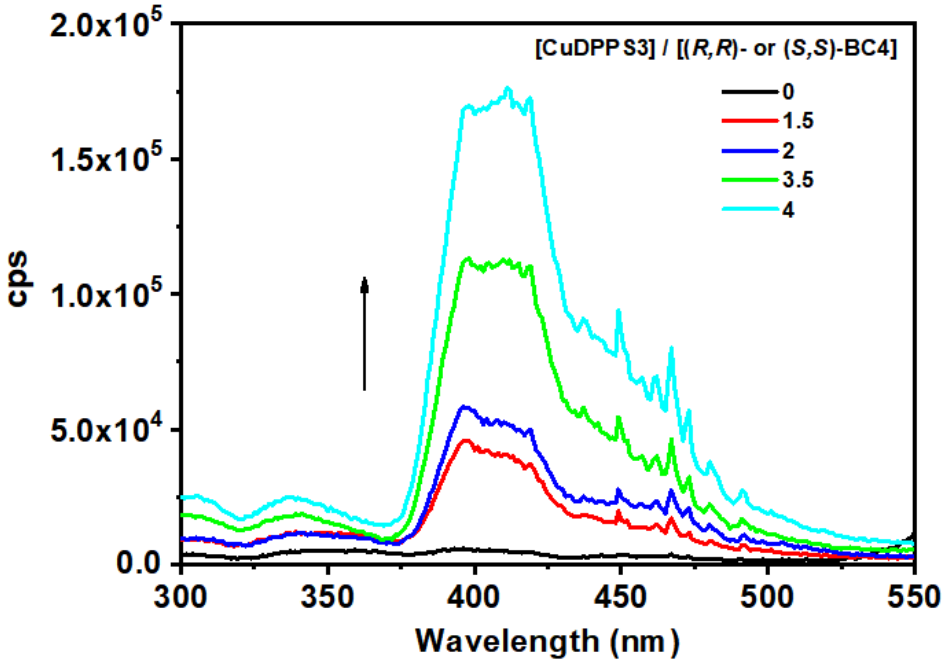

Fig. S12 RLS spectra observed at the break-points upon portion-wise addition of **CuDPPS3** to a 2.5 µM aqueous solution of (*R,R*)-**BC4** or (*S,S*)-**BC4** at pH 2.0 ([**CuDPPS3**] = 0 µM for black trace, ([**CuDPPS3**] = 3.75 µM for red trace, [**CuDPPS3**] = 5 µM for blue trace, [**CuDPPS3**] = 8.75 µM for green trace, [**CuDPPS3**] = 10 µM for cyan trace).

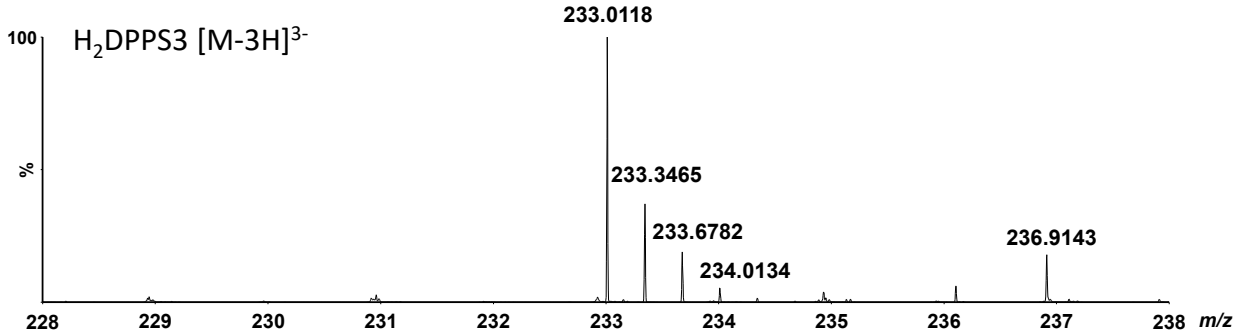

Fig. S13 High resolution mass spectra of the triply charged ion ([M-3H]$^{3-}$) of the porphyrin **H_2DPPS3**.

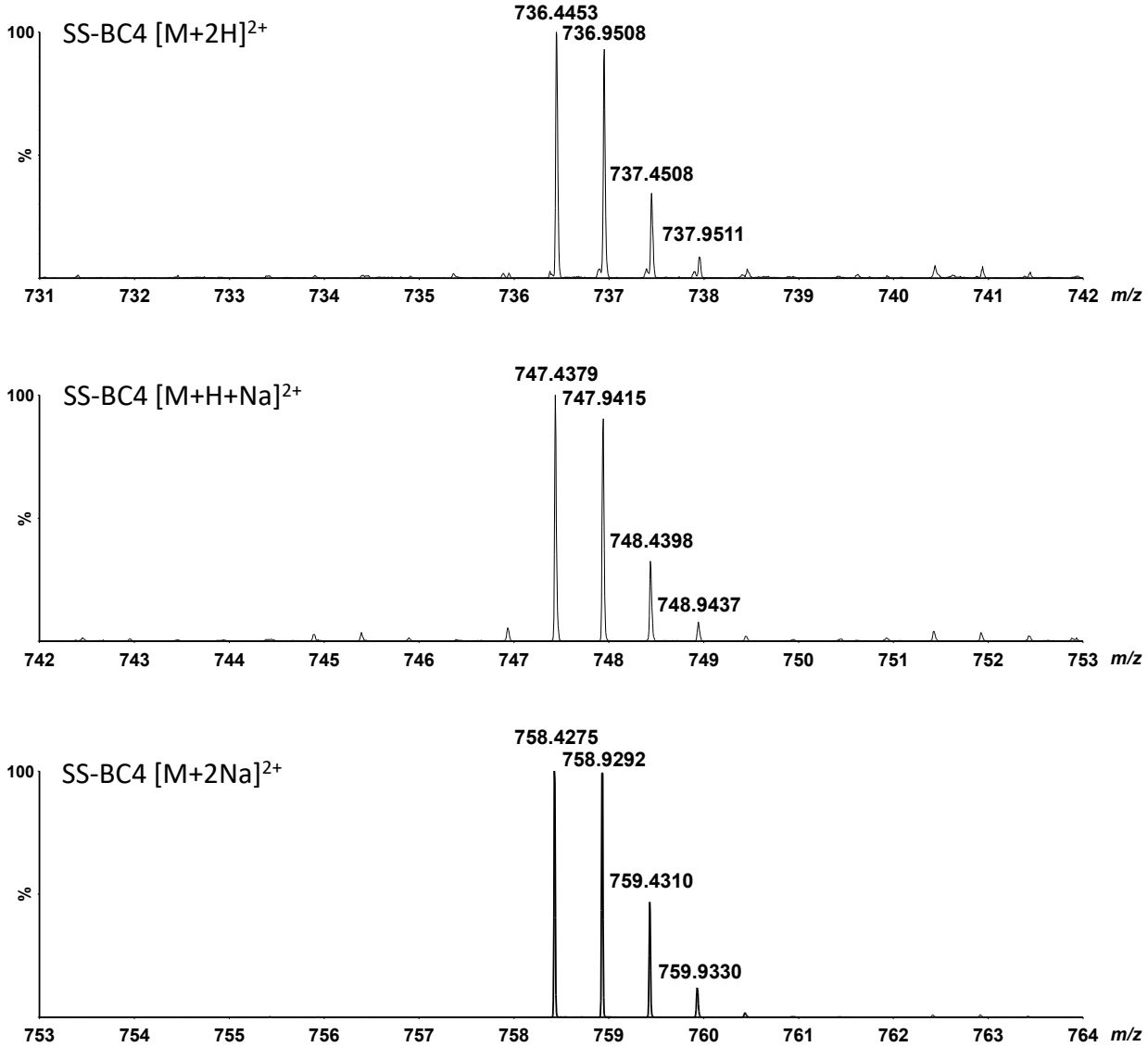

Fig. S14 High resolution mass spectra of the doubly charged ions ([M+2H]$^{2+}$, [M+H+Na]$^{2+}$ and [M+2Na]$^{2+}$) of the biscalixarene (*S,S*)-**BC4**.

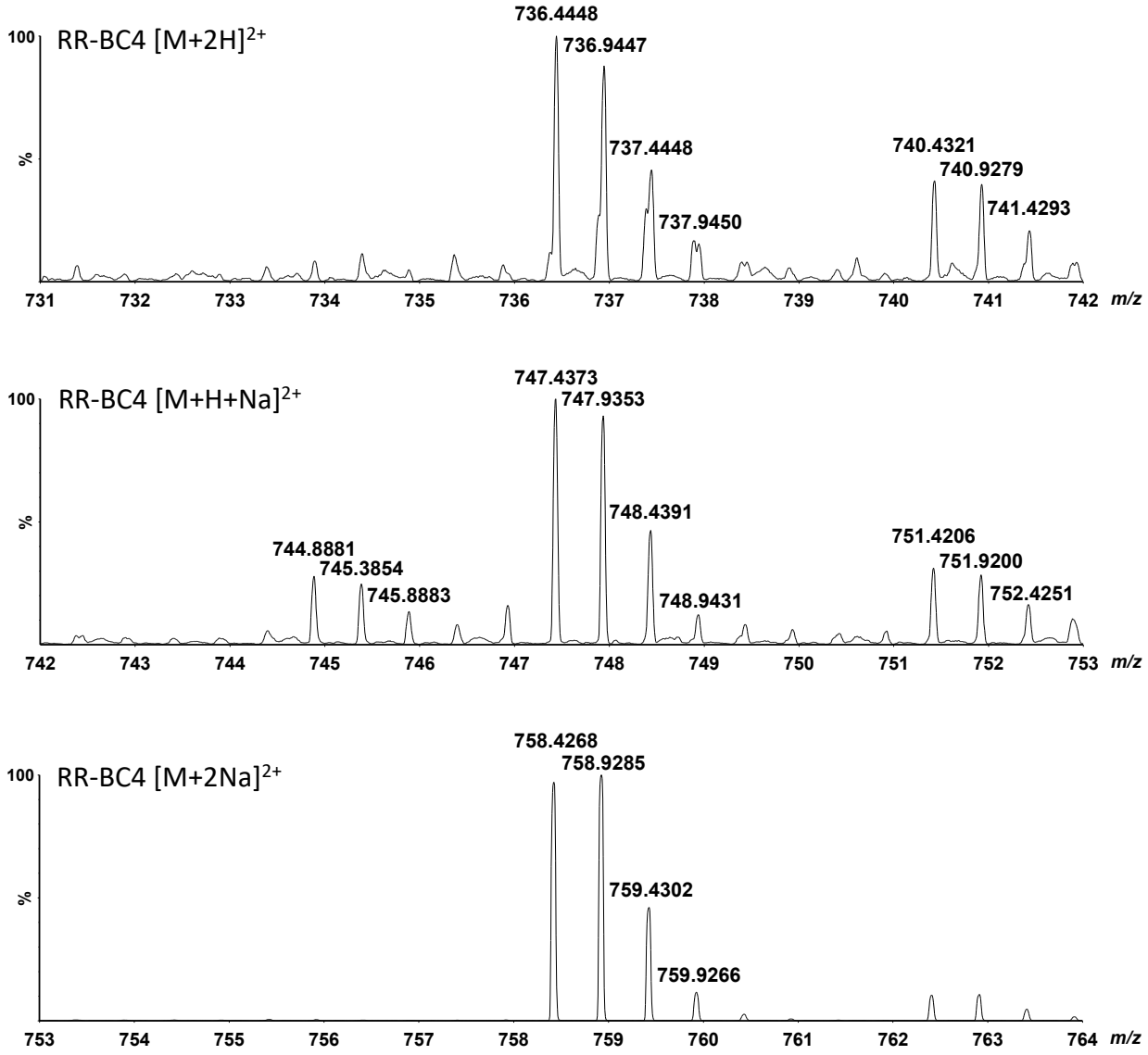

Fig. S15 High resolution mass spectra of the doubly charged ions ($[M+2H]^{2+}$, $[M+H+Na]^{2+}$ and $[M+2Na]^{2+}$) of the biscalixarene (*R,R*)-**BC4**.

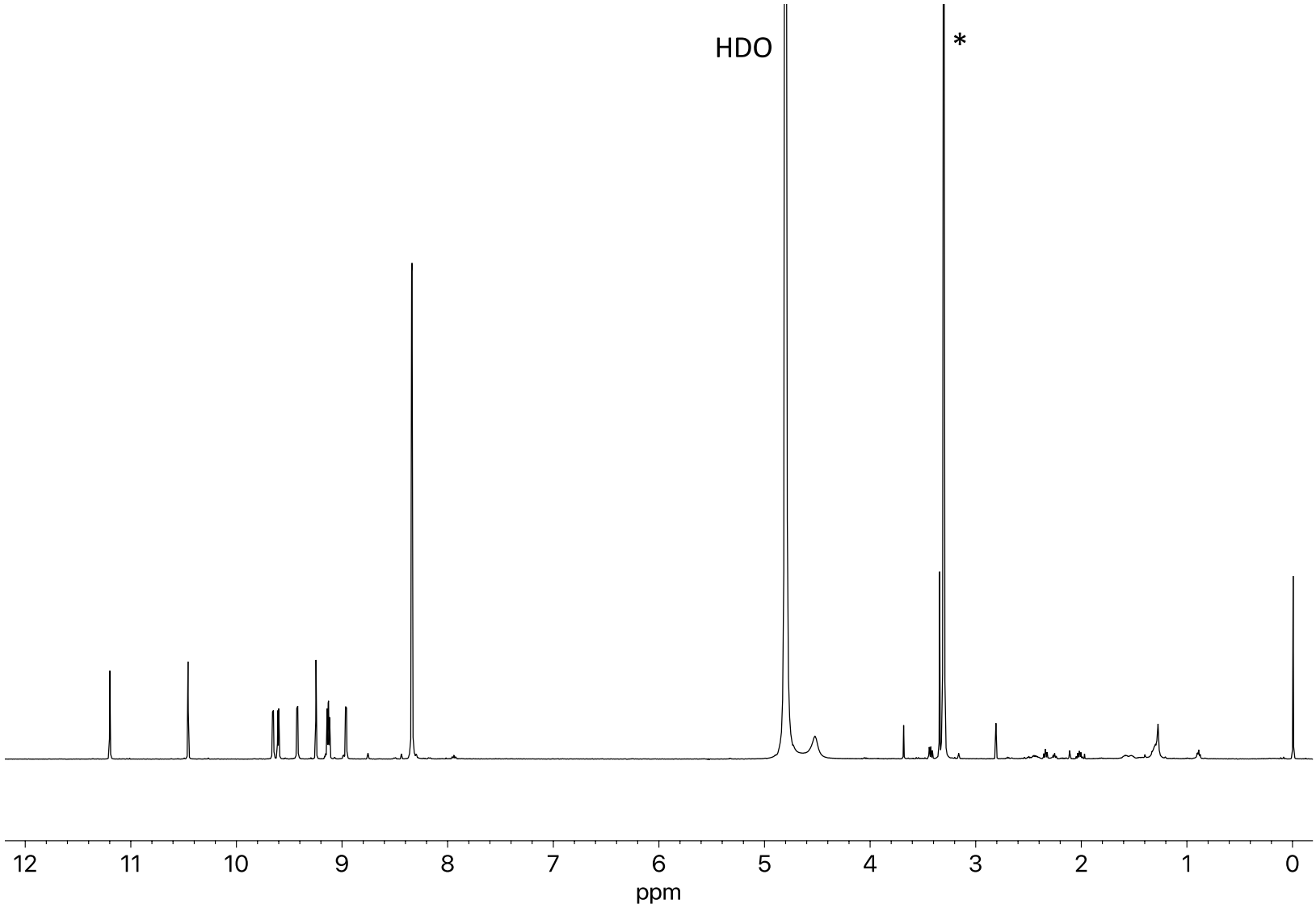

Fig. S16 ^{1}H NMR (500 MHz, 298 K, CD_3OD) of **H_2DPPS3**; (*) indicates the residual solvent peak.

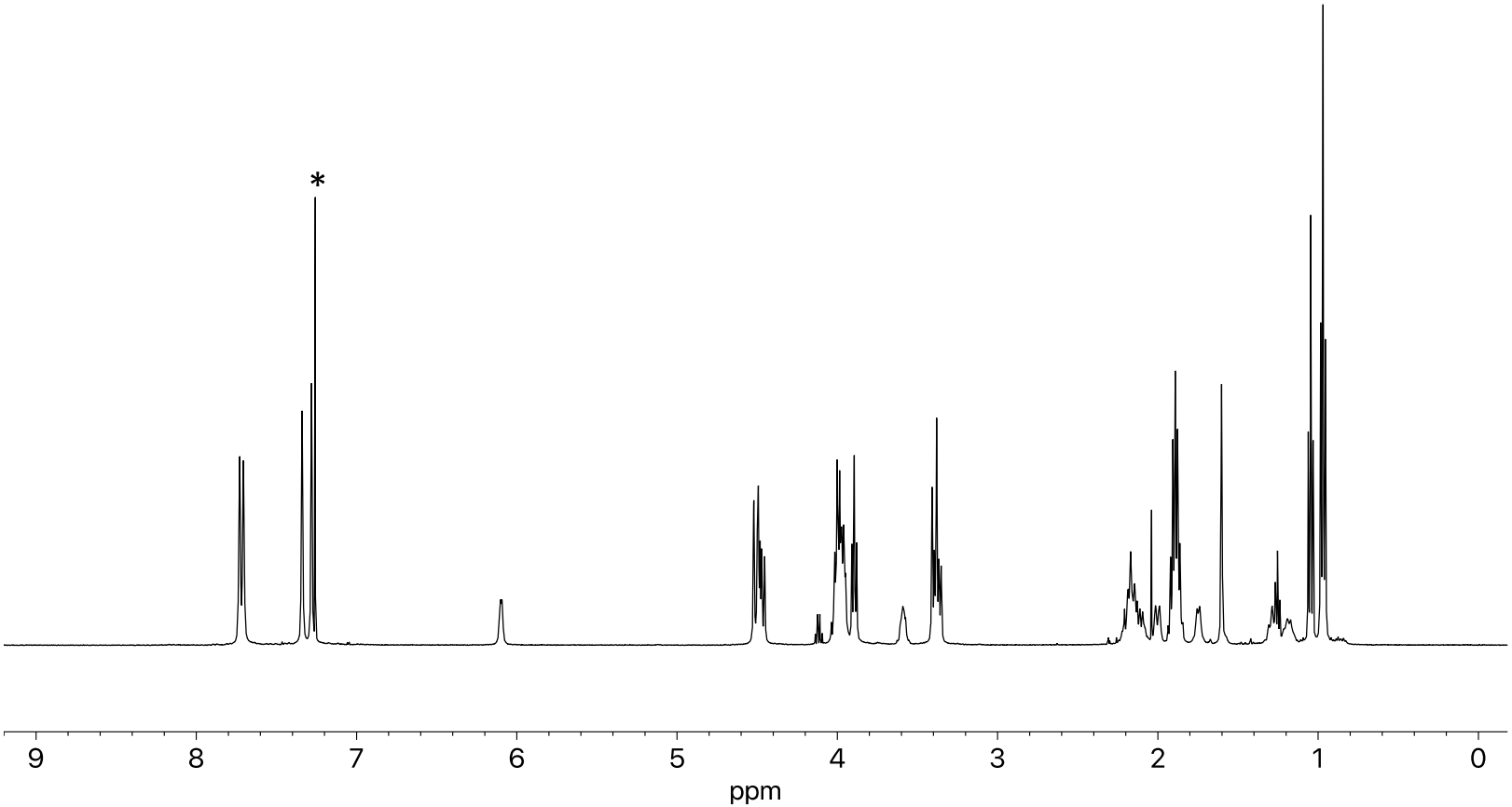

Fig. S17 ^{1}H NMR (500 MHz, 298 K, $CDCl_3$) of (*R*,*R*)-**8NO$_2$-BC4**; (*) indicates the residual solvent peak.

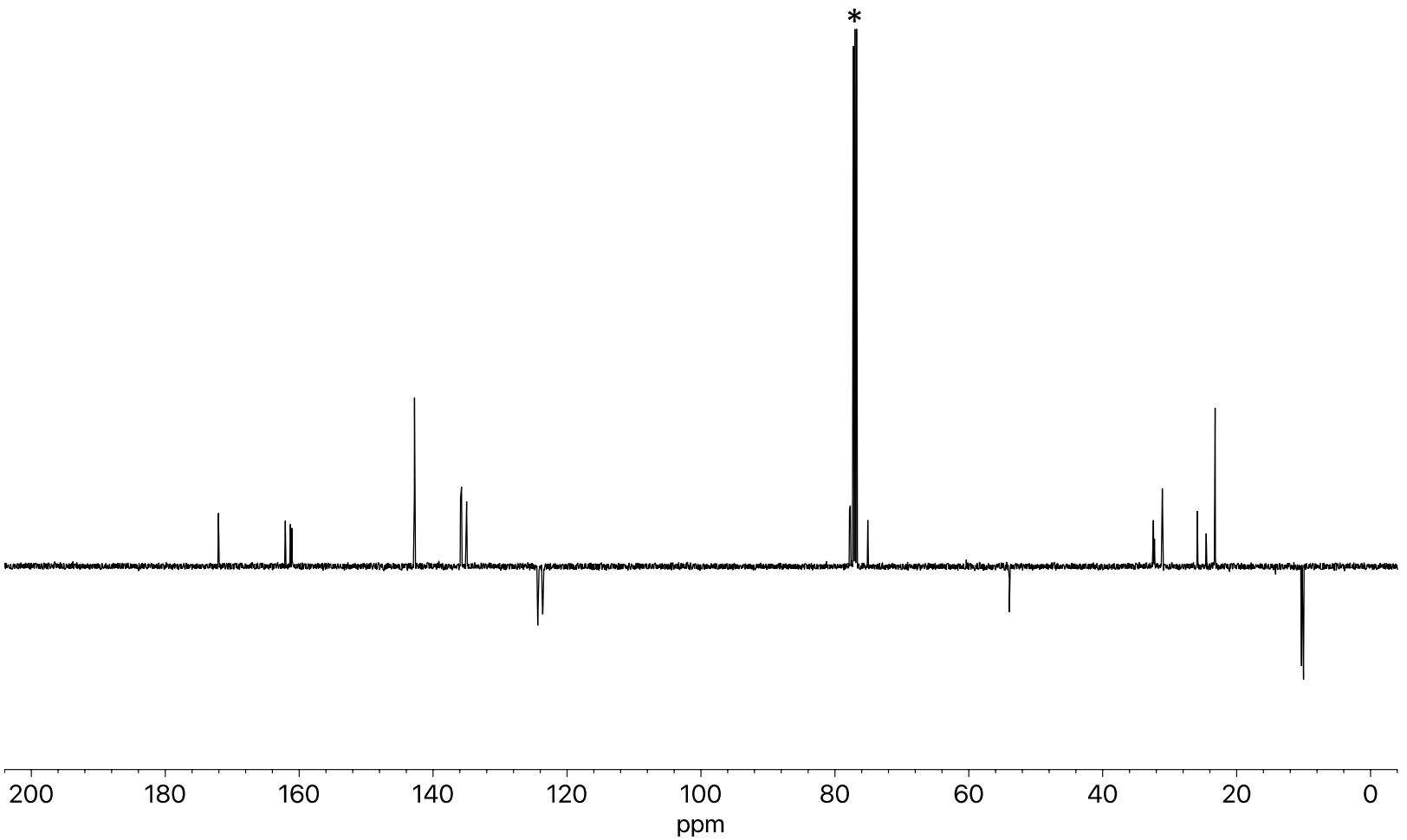

Fig. S18 ^{13}C (APT) NMR (500 MHz, 298 K, $CDCl_3$) of (*R*,*R*)-**8NO$_2$-BC4**; (*) indicates the residual solvent peak.

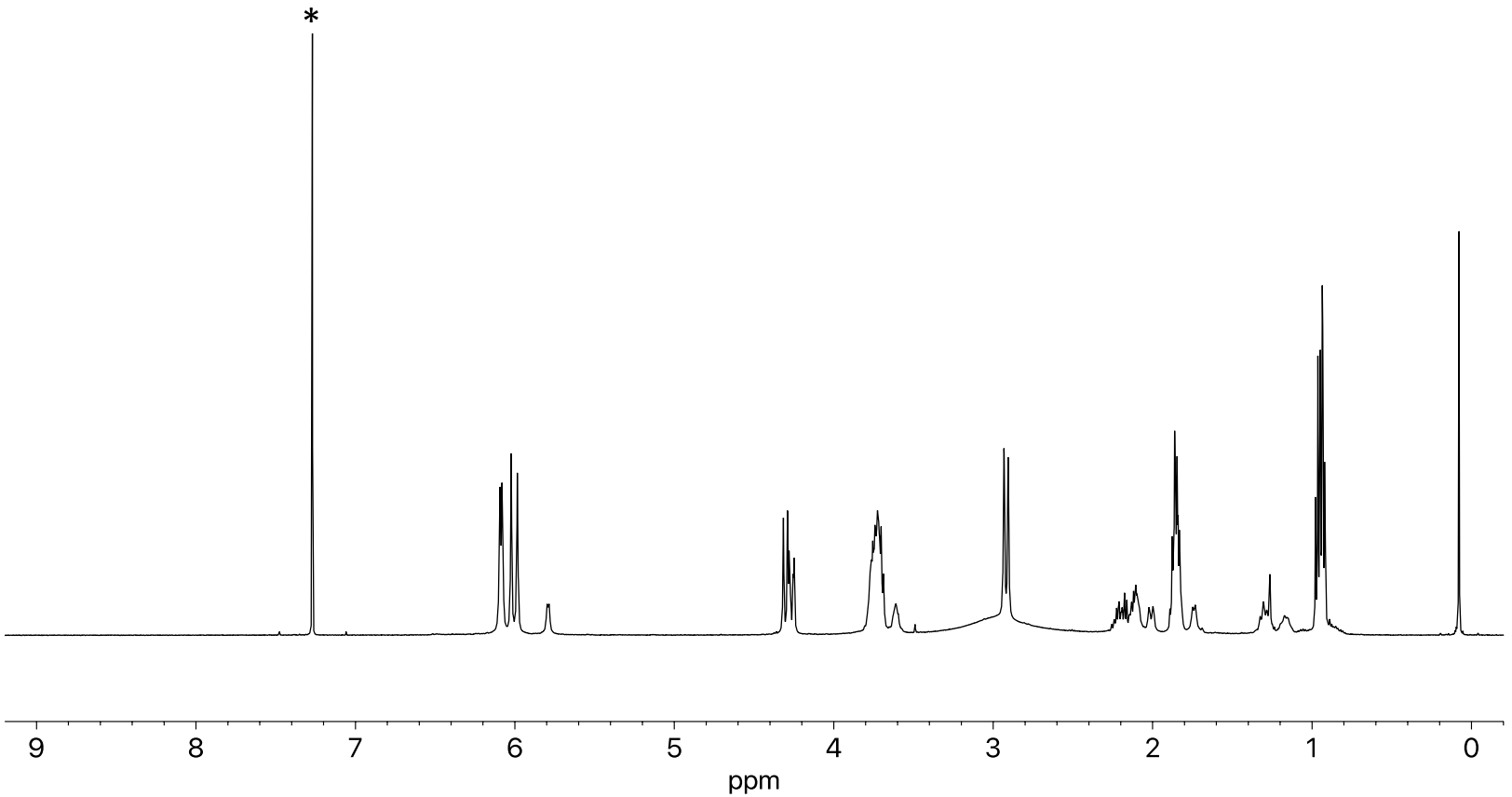

Fig. S19 ^{1}H NMR (500 MHz, 298 K, $CDCl_3$) of (*R*,*R*)-**8NH$_2$-BC4**; (*) indicates the residual solvent peak.

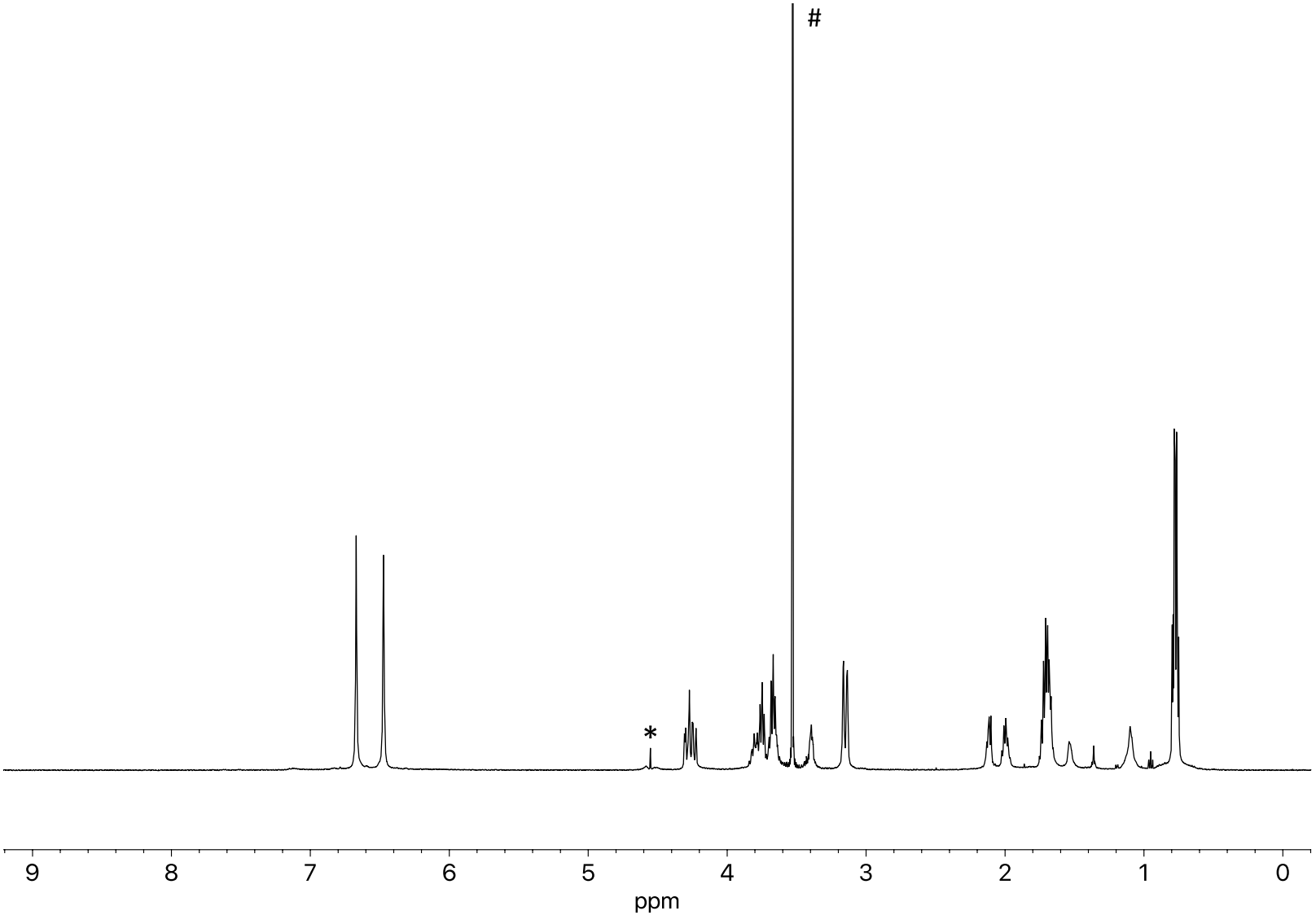

Fig. S20 ^{1}H NMR (500 MHz, 298 K, D_2O) of (*R*,*R*)-**BC4**; (*) indicates the suppressed residual solvent peak, (#) refers to dioxane added as an internal standard.

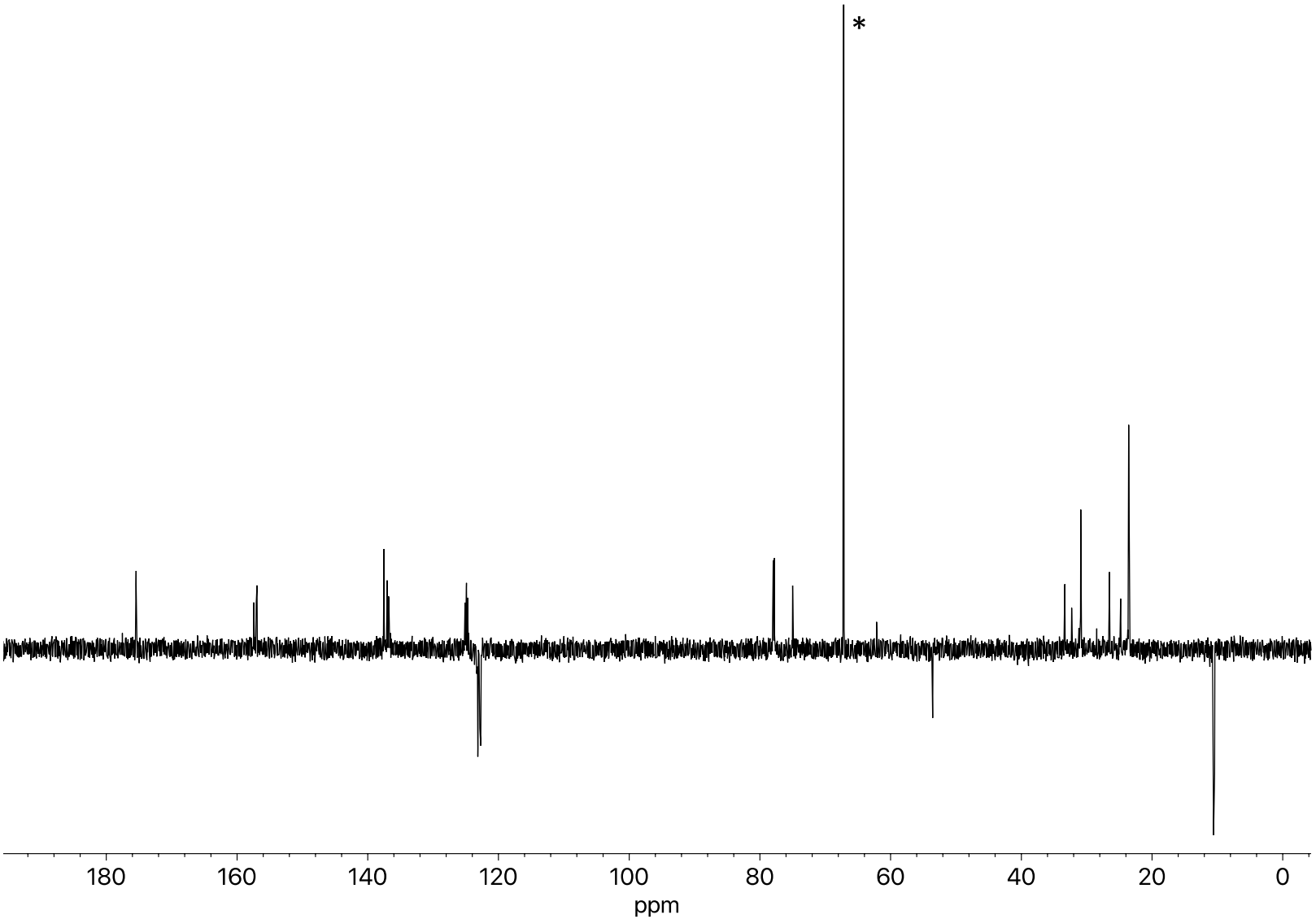

Fig. S21 ^{13}C (APT) NMR (500 MHz, 298 K, D_2O) of (*R*,*R*)-**BC4**; (*) refers to dioxane added as an internal standard.